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SUBSTRATE AND METHOD OF FORMING SUBSTRATE FOR FLUID EJECTION DEVICE

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The Field of the Invention

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The present invention relates generally to fluid ejection devices, and more particularly to a substrate for a fluid ejection device.

Background of the Invention

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In some fluid ejection devices, such as printheads, a drop ejecting element is formed on a substrate and fluid is routed to an ejection chamber of the drop ejecting element through an opening or slot in the substrate. Often, the substrate is a silicon wafer and the slot is formed in the wafer by chemical etching. Existing chemical etching processes, however, result in etch angles that cause a very wide backside opening of the slot in the substrate. The backside of the substrate is defined as a side of the substrate opposite of which the drop ejecting element is formed.

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Unfortunately, the wide backside slot opening limits how close to each other slots can be formed in a particular die. In addition, the wide backside slot opening reduces useful area of the backside of the substrate. For example, the wide backside slot opening reduces adhesion area of the backside of the substrate.

Accordingly, it is desired to minimize a size of the opening in the backside of the substrate.

Summary of the Invention

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One aspect of the present invention provides a method of forming an opening through a substrate. The method includes etching into the substrate from a first side so as to form a first portion of the opening, etching into the substrate from a second side opposite the first side so as to form a second portion of the opening, continuing etching into the substrate from at least one of the first side and the second side toward the other of the first side and the second side so as to communicate the first portion and the second portion of the opening, and etching into the substrate from an interface between the first portion and the second portion of the opening, including etching toward the second side of the substrate and forming a third portion of the opening.

Brief Description of the Drawings

Figure 1 is a block diagram illustrating one embodiment of an inkjet printing system according to the present invention.

Figure 2 is a schematic cross-sectional view illustrating one embodiment of a portion of a fluid ejection device according to the present invention.

Figures 3A - 3C illustrate one embodiment of an opening through a substrate according to the present invention.

Figure 3D illustrates one embodiment of a casting of the opening of Figure 3C.

Figures 4A - 4C illustrate another embodiment of an opening through a substrate according to the present invention.

Figure 4D illustrates one embodiment of a casting of the opening of Figure 4C.

Figures 5A - 5F are schematic cross-sectional end and side views illustrating one embodiment of forming an opening through a substrate according to the present invention.

Figures 6A - 6F are schematic cross-sectional end and side views illustrating another embodiment of forming an opening through a substrate according to the present invention.

Figure 7 is a top view illustrating one embodiment of a substrate including a pair of conventional openings therethrough.

Figure 8 is a top view illustrating one embodiment of a substrate including a pair of openings therethrough according to the present invention.

Figures 9A and 9B illustrate another embodiment of an opening through a substrate according to the present invention.

Figures 10A - 10F are schematic cross-sectional side views illustrating another embodiment of forming an opening through a substrate according to the present invention.

Figure 11A is a top perspective view illustrating one embodiment of a casting of a pair of openings through a substrate according to the present invention.

Figure 11B is a bottom perspective view of the casting of Figure 11A.

Figure 12 is a top view illustrating another embodiment of a substrate including a pair of openings therethrough according to the present invention.

Figure 13 is a top view illustrating another embodiment of a substrate including a pair of openings therethrough according to the present invention.

Description of the Preferred Embodiments

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. In this regard, directional terminology, such as "top," "bottom," "front," "back," "leading," "trailing," etc., is used with reference to the orientation of the Figure(s) being described. Because components of the

present invention can be positioned in a number of different orientations, the directional terminology is used for purposes of illustration and is in no way limiting. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present invention. The following detailed description, therefore, is not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims.

Figure 1 illustrates one embodiment of an inkjet printing system 10 according to the present invention. Inkjet printing system 10 includes an inkjet printhead assembly 12, an ink supply assembly 14, a mounting assembly 16, a media transport assembly 18, and an electronic controller 20. Inkjet printhead assembly 12 is formed according to an embodiment of the present invention, and includes one or more printheads or fluid ejection devices which eject drops of ink through a plurality of orifices or nozzles 13 and toward a print medium 19 so as to print onto print medium 19. Print medium 19 is any type of suitable sheet material, such as paper, card stock, transparencies, Mylar, and the like. Typically, nozzles 13 are arranged in one or more columns or arrays such that properly sequenced ejection of ink from nozzles 13 causes characters, symbols, and/or other graphics or images to be printed upon print medium 19 as inkjet printhead assembly 12 and print medium 19 are moved relative to each other.

Ink supply assembly 14 supplies ink to printhead assembly 12 and includes a reservoir 15 for storing ink. As such, ink flows from reservoir 15 to inkjet printhead assembly 12. Ink supply assembly 14 and inkjet printhead assembly 12 can form either a one-way ink delivery system or a recirculating ink delivery system. In a one-way ink delivery system, substantially all of the ink supplied to inkjet printhead assembly 12 is consumed during printing. In a recirculating ink delivery system, however, only a portion of the ink supplied to printhead assembly 12 is consumed during printing. As such, a portion of the ink not consumed during printing is returned to ink supply assembly 14.

In one embodiment, inkjet printhead assembly 12 and ink supply assembly 14 are housed together in an inkjet cartridge or pen. In another embodiment, ink supply assembly 14 is separate from inkjet printhead assembly

12 and supplies ink to inkjet printhead assembly 12 through an interface connection, such as a supply tube. In either embodiment, reservoir 15 of ink supply assembly 14 may be removed, replaced, and/or refilled. In one embodiment, where inkjet printhead assembly 12 and ink supply assembly 14 are housed together in an inkjet cartridge, reservoir 15 includes a local reservoir located within the cartridge and/or a larger reservoir located separately from the cartridge. As such, the separate, larger reservoir serves to refill the local reservoir. Accordingly, the separate, larger reservoir and/or the local reservoir may be removed, replaced, and/or refilled.

Mounting assembly 16 positions inkjet printhead assembly 12 relative to media transport assembly 18 and media transport assembly 18 positions print medium 19 relative to inkjet printhead assembly 12. Thus, a print zone 17 is defined adjacent to nozzles 13 in an area between inkjet printhead assembly 12 and print medium 19. In one embodiment, inkjet printhead assembly 12 is a scanning type printhead assembly. As such, mounting assembly 16 includes a carriage for moving inkjet printhead assembly 12 relative to media transport assembly 18 to scan print medium 19. In another embodiment, inkjet printhead assembly 12 is a non-scanning type printhead assembly. As such, mounting assembly 16 fixes inkjet printhead assembly 12 at a prescribed position relative to media transport assembly 18. Thus, media transport assembly 18 positions print medium 19 relative to inkjet printhead assembly 12.

Electronic controller 20 communicates with inkjet printhead assembly 12, mounting assembly 16, and media transport assembly 18. Electronic controller 20 receives data 21 from a host system, such as a computer, and includes memory for temporarily storing data 21. Typically, data 21 is sent to inkjet printing system 10 along an electronic, infrared, optical or other information transfer path. Data 21 represents, for example, a document and/or file to be printed. As such, data 21 forms a print job for inkjet printing system 10 and includes one or more print job commands and/or command parameters.

In one embodiment, electronic controller 20 provides control of inkjet printhead assembly 12 including timing control for ejection of ink drops from nozzles 13. As such, electronic controller 20 defines a pattern of ejected ink

drops which form characters, symbols, and/or other graphics or images on print medium 19. Timing control and, therefore, the pattern of ejected ink drops, is determined by the print job commands and/or command parameters. In one embodiment, logic and drive circuitry forming a portion of electronic controller 20 is located on inkjet printhead assembly 12. In another embodiment, logic and drive circuitry is located off inkjet printhead assembly 12.

Figure 2 illustrates one embodiment of a portion of inkjet printhead assembly 12. Inkjet printhead assembly 12 includes an array of printing or drop ejecting elements 30. Drop ejecting elements 30 are formed on a substrate 40 which has an ink feed slot 42 formed therein. As such, ink feed slot 42 provides a supply of liquid ink to drop ejecting elements 30. Each drop ejecting element 30 includes a thin-film structure 32, an orifice layer 34, and a firing resistor 38. Thin-film structure 32 has an ink feed channel 33 formed therein which communicates with ink feed slot 42 of substrate 40. Orifice layer 34 has a front face 35 and a nozzle opening 36 formed in front face 35. Orifice layer 34 also has a nozzle chamber 37 formed therein which communicates with nozzle opening 36 and ink feed channel 33 of thin-film structure 32. Firing resistor 38 is positioned within nozzle chamber 37 and includes leads 39 which electrically couple firing resistor 38 to a drive signal and ground.

During printing, ink flows from ink feed slot 42 to nozzle chamber 37 via ink feed channel 33. Nozzle opening 36 is operatively associated with firing resistor 38 such that droplets of ink are ejected from nozzle chamber 37 through nozzle opening 36 (e.g., normal to the plane of firing resistor 38) and toward a print medium upon energization of firing resistor 38.

Example embodiments of inkjet printhead assembly 12 include a thermal printhead, a piezoelectric printhead, a flex-tensional printhead, or any other type of fluid ejection device known in the art. In one embodiment, inkjet printhead assembly 12 is a fully integrated thermal inkjet printhead. As such, substrate 40 is formed, for example, of silicon, glass, or a stable polymer, and thin-film structure 32 is formed by one or more passivation or insulation layers of silicon dioxide, silicon carbide, silicon nitride, tantalum, poly-silicon glass, or other suitable material. Thin-film structure 32 also includes a conductive layer which

defines firing resistor 38 and leads 39. The conductive layer is formed, for example, by aluminum, gold, tantalum, tantalum-aluminum, or other metal or metal alloy.

5 Figures 3A - 3D illustrate one embodiment of an opening 50 through a substrate 60. Substrate 60 has a first side 62 and a second side 64. Second side 64 is opposite of first side 62 and, in one embodiment, oriented substantially parallel with first side 62. Opening 50 communicates with first side 62 and second side 64 of substrate 60 so as to provide a channel or passage through substrate 60.

10 In one embodiment, substrate 60 represents substrate 40 of inkjet printhead assembly 12 and opening 50 represents ink feed slot 42 formed in substrate 40. As such, drop ejecting elements 30 of inkjet printhead assembly 12 are formed on first side 62 of substrate 60. Thus, first side 62 forms a frontside of substrate 60 and second side 64 forms a backside of substrate 60 with ink flowing through opening 50 and, therefore, substrate 60 from the backside to the frontside. Accordingly, opening 50 provides a fluidic channel for the communication of ink with drop ejecting elements 30 through substrate 60.

15 As illustrated in the embodiment of Figure 3A, opening 50 includes a first portion 52 and a second portion 54. First portion 52 of opening 50 is formed in and communicates with first side 62 of substrate 60 and second portion 54 of opening 50 is formed in and communicates with second side 64 of substrate 60. As such, first portion 52 forms a hole 63 in first side 62 and second portion 54 forms a hole 65 in second side 64. First portion 52 and second portion 54 communicate with each other so as to form a portion of opening 50 through substrate 60.

20 In one embodiment, first portion 52 of opening 50 is in the form of an elongated slot or channel and has a substantially V-shaped or inverted, triangular-shaped cross-section. In another embodiment, first portion 52 of opening 50 has a substantially trapezoidal-shaped cross-section. In addition, in one embodiment, second portion 54 of opening 50 is in the form of a polyhedron and has a substantially triangular-shaped cross-section. In another embodiment, second portion 54 of opening 50 has a substantially trapezoidal-

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shaped cross-section. Preferably, a valley of first portion 52 communicates with a tip of second portion 54. As such, first portion 52 and second portion 54 communicate or connect to form a portion of opening 50 through substrate 60.

As illustrated in the embodiment of Figure 3B, opening 50 also includes a
5 third portion 56. Third portion 56 of opening 50 is formed in substrate 60 and extends between first portion 52 and second portion 54 of opening 50. More specifically, third portion 56 extends from an interface 55 formed between first portion 52 and second portion 54 toward second side 64. One embodiment of forming third portion 56 by overetching first portion 52 and second portion 54 is
10 illustrated and described below with reference to Figures 5D - 5F.

One side of third portion 56 communicates with first portion 52, an adjacent side of third portion 56 communicates with second portion 54, and another side of third portion 56 extends from second side 64 toward first side 62 to first portion 52. Thus, third portion 56 communicates with first portion 52 and
15 second portion 54 so as to form an additional portion of opening 50 through substrate 60. In one embodiment, third portion 56 extends from two opposing sides of second portion 54. It is, however, within the scope of the present invention for third portion 56 to extend only from one side of second portion 54.

In one embodiment, as described below, third portion 56 is formed by
20 etching along a low-index plane of substrate 60. As such, third portion 56 of opening 50 has a substantially triangular-shaped profile and a substantially trapezoidal-shaped cross-section which diminishes in size between second portion 54 and first portion 52. More specifically, the substantially trapezoidal-shaped cross-section of third portion 56 diminishes in size from a side of second
25 portion 54 of opening 50 toward an end of first portion 52 of opening 50. As such, a base of third portion 56 communicates with a side of second portion 54 and a tip of third portion 56 communicates with first portion 52.

As illustrated in the embodiment of Figure 3C, first portion 52, second portion 54, and third portion 56 communicate with each other to form opening
30 50 through substrate 60. More specifically, first portion 52, second portion 54, and third portion 56 combine to communicate hole 63 in first side 62 with hole

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65 in second side 64. As such, opening 50 provides a channel or passage through substrate 60.

For clarity of the invention, a casting 70 of opening 50 through substrate 60 is illustrated in the embodiment of Figure 3D. With casting 70, the combined
5 opening 50 created by first portion 52, second portion 54, and third portion 56 is illustrated in solid form.

First portion 52, second portion 54, and third portion 56 of opening 50 are formed according to an embodiment of the present invention, as described below. First portion 52 may be formed before, after, and/or at the same time as
10 second portion 54 or second portion 54 may be formed before, after, and/or at the same time as first portion 52. In one embodiment, first portion 52 of opening 50 is formed first and self-terminates within substrate 60. As such, second portion 54 of opening 50 is formed second so as to communicate with first portion 52. In another embodiment, second portion 54 of opening 50 is formed
15 first and self-terminates within substrate 60. As such, first portion 52 of opening 50 is formed second so as to communicate with second portion 54. In another embodiment, first portion 52 and second portion 54 of opening 50 are formed at the same time. As such, first portion 52 of opening 50 self-terminates within substrate 60 and second portion 54 of opening 50 is formed so as to
20 communicate with first portion 52.

Figures 4A - 4D illustrate another embodiment of opening 50 through substrate 60. Opening 50', similar to opening 50, communicates with first side 62 and second side 64 of substrate 60 so as to provide a channel or passage through substrate 60. As illustrated in the embodiment of Figure 4A, opening
25 50' includes first portion 52 and second portion 54, as described above with reference to opening 50.

As illustrated in the embodiment of Figure 4B, opening 50' also includes a third portion 56'. Third portion 56' of opening 50', similar to third portion 56 of opening 50, is formed in substrate 60 and extends between first portion 52 and
30 second portion 54 of opening 50'. More specifically, third portion 56' extends from interface 55 formed between first portion 52 and second portion 54 toward second side 64. One embodiment of forming third portion 56' by overetching

first portion 52 and second portion 54 is illustrated and described below with reference to Figures 6D - 6F.

One side of third portion 56' communicates with first portion 52, an adjacent side of third portion 56' communicates with second portion 54, and another side of third portion 56' extends from second side 64 toward first side 62 to first portion 52. Thus, third portion 56' communicates with first portion 52 and second portion 54 so as to form an additional portion of opening 50' through substrate 60. In one embodiment, third portion 56' extends from two opposing sides of second portion 54. It is, however, within the scope of the present invention for third portion 56' to extend only from one side of second portion 54.

In one embodiment, as described below, third portion 56' is formed by etching along a high-index plane of substrate 60. As such, third portion 56' of opening 50' is in the form of a polyhedron oriented or tipped at an angle and having a substantially diamond-shaped base. Thus, third portion 56' has a substantially diamond-shaped cross-section which diminishes in size between second portion 54 and first portion 52. More specifically, the substantially diamond-shaped cross-section of third portion 56' diminishes in size from a side of second portion 54 of opening 50' toward an end of first portion 52 of opening 50'. As such, a base of third portion 56' communicates with a side of second portion 54 and a tip of third portion 56' communicates with first portion 52. In addition, third portion 56' forms a compound surface between first portion 52 and second portion 54 of opening 50'. The compound surface includes, for example, opposing substantially V-shaped surfaces which extend between and diminish from a side of second portion 54 toward an end of first portion 52.

As illustrated in the embodiment of Figure 4C, first portion 52, second portion 54, and third portion 56' communicate with each other to form opening 50' through substrate 60. More specifically, first portion 52, second portion 54, and third portion 56' combine to communicate hole 63 in first side 62 with hole 65 in second side 64. As such, opening 50' provides a channel or passage through substrate 60.

For clarity of the invention, a casting 70' of opening 50' through substrate 60 is illustrated in the embodiment of Figure 4D. With casting 70', the combined

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opening 50' created by first portion 52, second portion 54, and third portion 56' is illustrated in solid form.

First portion 52, second portion 54, and third portion 56' of opening 50' are formed according to an embodiment of the present invention, as described below. In addition, first portion 52 may be formed before, after, and/or at the same time as second portion 54 or second portion 54 may be formed before, after, and/or at the same time as first portion 52, as described above with reference to opening 50.

Figures 5A - 5F and Figures 6A - 6F illustrate one embodiment of forming opening 50 and opening 50', respectively, through substrate 60. Figures 5A - 5F and Figures 6A - 6F each include schematic cross-sectional end and side views of forming opening 50 and opening 50', respectively, through substrate 60. Accordingly, the schematic side views represent cross-sectional views in a first direction and the schematic end views represent cross-sectional views in a second direction substantially perpendicular to the first direction. While only one opening 50 and one opening 50' is illustrated as being formed, it is understood that multiple openings 50 and/or 50' may be formed through substrate 60.

In one embodiment, substrate 60 is a silicon substrate and openings 50 and 50' are formed in substrate 60 by chemical etching. Preferably, openings 50 and 50' are formed using anisotropic chemical etch processes. More specifically, the chemical etch processes are wet etch processes and use a wet anisotropic etchant such as tetra-methyl ammonium hydroxide (TMAH), potassium hydroxide (KOH), or other alkaline etchant. As such, the geometry of openings 50 and 50' through substrate 60 is defined by crystalline planes of the silicon substrate, as described below. Different crystalline planes of the silicon substrate are etched, for example, by varying a concentration of the wet anisotropic etchant.

As illustrated in the embodiments of Figures 5A and 6A, before substrate 60 is etched, masking layers 72 and 74 are formed on substrate 60. More specifically, masking layer 72 is formed on first side 62 of substrate 60 and masking layer 74 is formed on second side 64 of substrate 60. Masking layers 72 and 74 are used to selectively control or block etching of first side 62 and

second side 64, respectively. As such, masking layer 72 is formed along first side 62 of substrate 60 and patterned to expose areas of first side 62 and define where substrate 60 is to be etched to form hole 63 and first portion 52 of openings 50 and 50'. In addition, masking layer 74 is formed along second side 64 of substrate 60 and patterned to expose areas of second side 64 and define where substrate 60 is to be etched to form hole 65 and second portion 54 of openings 50 and 50'. It is understood that masking layers 72 and/or 74 may include one or more layers formed on first side 62 and second side 64, respectively.

In one embodiment, masking layers 72 and 74 are formed by deposition and patterned by photolithography and etching to define exposed portions of first side 62 and second side 64 of substrate 60. More specifically, masking layer 72 is patterned to outline hole 63 in first side 62 and first portion 52 of openings 50 and 50' to be formed in substrate 60 from first side 62. In addition, masking layer 74 is patterned to outline hole 65 in second side 64 and second portion 54 of openings 50 and 50' to be formed in substrate 60 from second side 64. Masking layers 72 and 74 are each formed of a material which is resistant to etchant used for etching substrate 60, as described above. Examples of a material suitable for masking layers 72 and 74 include silicon dioxide or silicon nitride.

Next, as illustrated in the embodiments of Figures 5B and 6B, hole 63 is etched in first side 62 of substrate 60 and hole 65 is etched in second side 64 of substrate 60. As such, hole 63 is formed as a portion of first portion 52 of openings 50 and 50' and hole 65 is formed as a portion of second portion 54 of openings 50 and 50'. Thus, first portion 52 of openings 50 and 50' is formed by etching substrate 60 from first side 62 toward second side 64 and second portion 54 of openings 50 and 50' is formed by etching substrate 60 from second side 64 toward first side 62.

Preferably, first portion 52 and second portion 54 of openings 50 and 50' are formed using anisotropic wet etch processes, as described above. As such, first portion 52 of openings 50 and 50' follows a crystalline plane 76 of substrate 60 and second portion 54 of openings 50 and 50' follows a crystalline plane 77

of substrate 60. In one embodiment, substrate 60 has a $\langle 100 \rangle$ Si crystal orientation and the wet anisotropic etches of first portion 52 and second portion 54 follow $\langle 111 \rangle$ Si planes of substrate 60. As such, crystalline planes 76 and 77 include $\langle 111 \rangle$ Si planes of substrate 60. Thus, sides of first portion 52 of openings 50 and 50' and sides of second portion 54 of openings 50 and 50' are oriented at an angle of approximately 54 degrees. The $\langle 111 \rangle$ Si planes of substrate 60 are binary ("0", "1") planes and represent low-index planes of substrate 60. Other examples of low-index planes which may be used when using wafers having different crystal orientations include $\langle 100 \rangle$ and $\langle 110 \rangle$ Si planes.

As illustrated in the embodiments of Figures 5C and 6C, etching into substrate 60 from first side 62 toward second side 64 and/or from second side 64 toward first side 62 continues such that first portion 52 of openings 50 and 50' and second portion 54 of openings 50 and 50' connect or communicate. As such, interface 55 is formed between first portion 52 and second portion 54. In addition, first portion 52 of openings 50 and 50' converges from first side 62 toward second side 64 and second portion 54 of openings 50 and 50' converges from second side 64 toward first side 62. As such, first portion 52 of openings 50 and 50' is widest at first side 62 and second portion 54 of openings 50 and 50' is widest at second side 64. As described above, first portion 52 of openings 50 and 50' may be formed before, after, and/or at the same time as second portion 54, and second portion 54 of openings 50 and 50' may be formed before, after, and/or at the same time as first portion 52.

Next, as illustrated in the embodiments of Figures 5D and 6D, third portion 56 of opening 50 and third portion 56' of opening 50' are formed by etching substrate 60 at interface 55 between first portion 52 and second portion 54 of opening 50 and opening 50', respectively. In one embodiment, substrate 60 is etched from interface 55 toward first side 62 of substrate 60 and from interface 55 toward second side 64 of substrate 60. More specifically, third portions 56 and 56' are each formed by etching substrate 60 from interface 55 toward first side 62 at an angle relative to first side 62, as illustrated in the end view of Figures 5D and 6D, and from interface 55 toward second side 64 at an

angle relative to second side 64, as illustrated in the side view of Figures 5D and 6D. As such, first portion 52 and second portion 54 are each overetched to form third portions 56 and 56'. Preferably, the angle at which third portions 56 and 56' are etched is non-parallel and non-orthogonal to first side 62 and/or second side 64.

Preferably, third portion 56 of opening 50 and third portion 56' of opening 50' are each formed using an anisotropic etch process, as described above. As such, third portion 56 of opening 50 and third portion 56' of opening 50' each follow a crystalline plane 78 of substrate 60. In one embodiment, the wet anisotropic etch of third portion 56 follows $\langle 111 \rangle$ Si planes of substrate 60 such that sides of third portion 56 of opening 50 are oriented at an angle of approximately 54 degrees. Thus, crystalline plane 78 of third portion 56 includes $\langle 111 \rangle$ Si planes of substrate 60. The $\langle 111 \rangle$ Si planes of substrate 60 are binary planes and represent low-index planes of substrate 60. In one embodiment, the wet anisotropic etch of third portion 56' follows $\langle 310 \rangle$ Si planes of substrate 60 such that sides of third portion 56' of opening 50' are oriented at an angle of approximately 18 degrees. Thus, crystalline plane 78 of third portion 56' includes $\langle 310 \rangle$ Si planes of substrate 60. The $\langle 310 \rangle$ Si planes of substrate 60 are non-binary planes and represent high-index planes of substrate 60. Other examples of high-index planes include $\langle 210 \rangle$, $\langle 311 \rangle$, $\langle 711 \rangle$, and $\langle 510 \rangle$ Si planes.

As illustrated in the embodiments of Figures 5E and 6E, etching into substrate 60 from interface 55 toward first side 62 continues at an angle to first side 62 and etching into substrate 60 from interface 55 toward second side 64 continues at an angle to second side 64 of substrate 60. By etching third portion 56 of opening 50 and third portion 56' of opening 50' along one or more opposing sides of first portion 52 and second portion 54 of openings 50 and 50', respectively, first portion 52 and second portion 54 of openings 50 and 50' are overetched.

As illustrated in the embodiments of Figures 5F and 6F, etching into substrate 60 from interface 55 toward first side 62 and second side 64 continues such that third portion 56 of opening 50 and third portion 56' of opening 50' each

communicate second side 64 of substrate 60 with first portion 52 of openings 50 and 50', respectively. As such, third portion 56 of opening 50 and third portion 56' of opening 50' each communicate hole 65 in second side 64 with first portion 52 of openings 50 and 50', respectively, and, therefore, hole 63 in first side 62.

- 5 Preferably, etching of third portion 56 of opening 50 and third portion 56' of opening 50' at an angle from interface 55 toward first side 62 and second side 64 minimizes lateral or horizontal areas of openings 50 and 50', respectively, through substrate 60 from second side 64 to first side 62.

- 10 In one embodiment, etching of third portion 56 of opening 50 and third portion 56' of opening 50' at an angle from interface 55 toward first side 62 and second side 64 includes, in a first direction, diverging second portion 54 of openings 50 and 50' from second side 64 toward first side 62 of substrate 60 and, in a second direction substantially perpendicular to the first direction, converging second portion 54 of openings 50 and 50' from second side 64 toward first side 62 of substrate 60. As such, in one direction, second portion 54 of openings 50 and 50' is widest toward first side 62. Accordingly, in one direction, as illustrated in the side view of Figures 5F and 6F, openings 50 and 50' diverge from second side 64 toward first side 62 and, in another direction, as illustrated in the end view of Figures 5F and 6F, openings 50 and 50' converge from second side 64 toward first side 62. Thus, in one direction, hole 65 is wider than hole 63. In another direction, however, hole 63 is longer than hole 65.

- 25 Figures 7 and 8 each illustrate a pair of openings formed through substrate 60 according to conventional methods and according to the present invention, respectively. As illustrated in Figure 7, openings 90a and 90b are formed through substrate 60 according to conventional methods including conventional etching techniques, and each include a slot 92 formed in a first or frontside of substrate 60 and a slot 94 formed in a second or backside of substrate 60. By using conventional etching techniques, however, slot 94 is formed as a single elongated slot or trench.

Unfortunately, with slot 94 being formed as a single elongated trench, a significant amount of material is removed from substrate 60 including, more

specifically, the backside of substrate 60. As such, strength of substrate 60 is compromised and workable or useful area of the backside of substrate 60 is reduced. In addition, to accommodate multiple openings 90a and 90b in substrate 60, openings 90a and 90b must be spaced a sufficient distance from each other and from the ends of substrate 60 to accommodate substrate design restraints or requirements such as strength and backside support and/or adhesion area between and/or around openings 90a and 90b.

As illustrated in the embodiment of Figure 8, however, openings 50a and 50b formed through substrate 60 according to the present invention each include first portion 52 formed from first side 62 of substrate 60, second portion 54 formed from second side 64 of substrate 60, and third portion 56 (including third portion 56') formed between second portion 54 and first portion 52, as described above. As such, first portion 52 of each opening 50a and 50b forms a single elongated slot in first side 62 of substrate 60 and second portion 54 of each opening 50a and 50b forms a shorter slot in second side 64 of substrate 60.

By forming opening 50 (including opening 50') in substrate 60 with first portion 52, second portion 54, and third portion 56 (including third portion 56'), a slot of reduced size can feed a single elongated slot. More specifically, by overetching second portion 54 of opening 50 and forming third portion 56 of opening 50 between second portion 54 and first portion 52, hole 65 in second side 64 can be shorter than hole 63 in first side 62 since, in one direction, third portion 56 diverges or increases a dimension of opening 50 from second side 64 toward first side 62. As such, extension of the ends of hole 65 beyond the ends of hole 63 is eliminated. Accordingly, a dimension or area between an end of hole 63 in first side 62 and an end of substrate 60, commonly referred to as headland, can be reduced since the ends of hole 65 no longer extend beyond the ends of hole 63.

In addition, due to the converging or decreasing dimension of opening 50 (including opening 50') in one axis from second side 64 of substrate 60 toward first side 62 of substrate 60, and the diverging or increasing dimension of opening 50 (including opening 50') in another axis from second side 64 of

substrate 60 toward first side 62 of substrate 60, lateral flow areas which are conducive to forming bubble trap areas are avoided in opening 50. Thus, by forming opening 50 in substrate 60 with first portion 52, second portion 54, and third portion 56 extending between second portion 54 and first portion 52, opening 50 is outgassing friendly and provides no apparent bubble traps.

Figures 9A and 9B illustrate another embodiment of opening 50 through substrate 60. Opening 150, similar to openings 50 and 50', communicates with first side 62 and second side 64 of substrate 60 and provides a channel or passage through substrate 60. In addition, similar to openings 50 and 50', opening 150 includes a first portion 152 formed in and communicating with first side 62 of substrate 60. As such, similar to first portion 52, first portion 152 forms hole 63 in first side 62.

Opening 150, however, includes a plurality of second portions 154a, 154b formed in and communicating with second side 64 of substrate 60. As such, second portions 154a, 154b form respective holes 65a, 65b in second side 64. Accordingly, opening 150 also includes a plurality of third portions 156a, 156b formed in substrate 60 and extending between first portion 152 and respective second portions 154a, 154b of opening 150. More specifically, third portions 156a, 156b each have a side communicating with first portion 152, a side communicating with respective second portions 154a, 154b, and a side extending from second side 64 toward first side 62 to first portion 152. Thus, first portion 152, second portions 154a, 154b, and third portions 156a, 156b combine to form opening 150 through substrate 60.

Preferably, second portions 154a and 154b are spaced along second side 64. In one embodiment, second portions 154a and 154b are spaced such that adjacent third portions 156a and 156b extending between first portion 152 and respective adjacent second portions 154a and 154b communicate. More specifically, third portion 156a extending between first portion 152 and second portion 154a communicates with third portion 156b extending between first portion 152 and second portion 154b. As such, adjacent second portions 154a, 154b communicate via respective third portions 156a, 156b and holes 65a and 65b in second side 64 each communicate with hole 63 in first side 62. More

specifically, hole 65a communicates with hole 63 via second portion 154a, third portion 156a, and first portion 152, and hole 65b communicates with hole 63 via second portion 154b, third portion 156b, and first portion 152. As third portions 156a, 156b are formed by overetching respective second portions 154a, 154b, adjacent second portions 154a, 154b directly communicate.

Figures 10A - 10F illustrate one embodiment of forming opening 150 through substrate 60. While only one opening 150 is illustrated as being formed, it is understood that multiple openings 150 may be formed through substrate 60. As illustrated in the embodiment of Figure 10A, masking layers 72 and 74' are formed on substrate 60. Masking layers 72 and 74' are used to selectively control or block etching of first side 62 and second side 64, respectively, of substrate 60. Masking layers 72 and 74' are formed and patterned, as described above, with the exception that masking layer 74' is patterned to define a plurality of exposed portions of second side 64 of substrate 60.

Next, as illustrated in the embodiment of Figure 10B, first portion 152 of opening 150 is formed by etching substrate 60 from first side 62 toward second side 64 and second portions 154a, 154b are formed by etching substrate 60 from second side 64 toward first side 62. Preferably, first portion 152 and second portions 154a, 154b are formed using anisotropic wet etch processes, as described above. As such, first portion 152 of opening 150 follows crystalline plane 76 of substrate 60 and second portions 154a, 154b of opening 150 follow crystalline planes 77 of substrate 60. In one embodiment, crystalline plane 76 and crystalline planes 77 include $\langle 111 \rangle$ Si planes of substrate 60, as described above.

As illustrated in the embodiment of Figure 10C, etching into substrate 60 from first side 62 toward second side 64 and/or from second side 64 toward first side 62 continues such that first portion 152 of opening 150 and second portions 154a, 154b of opening 150 connect or communicate. As such, interfaces 155a, 155b are formed between first portion 152 and respective second portions 154a, 154b.

Next, as illustrated in the embodiment of Figure 10D, third portions 156a, 156b of opening 150 are formed by etching substrate 60 from respective interfaces 155a, 155b between first portion 152 and respective second portions 154a, 154b toward first side 62 of substrate 60 and toward second side 64 of substrate 60. Preferably, third portions 156a, 156b of opening 150 are formed using an anisotropic etch process, as described above. As such, third portions 156a, 156b of opening 150 follow crystalline planes 78 of substrate 60. In one embodiment, crystalline planes 78 include low-index planes such as $\langle 111 \rangle$ Si planes of substrate 60. In another embodiment, crystalline planes 78 include high-index planes such as $\langle 310 \rangle$ Si planes of substrate 60.

As illustrated in the embodiment of Figure 10E, etching into substrate 60 from interfaces 155a, 155b toward first side 62 continues at an angle to first side 62 and etching into substrate 60 from interfaces 155a, 155b toward second side 64 continues at an angle to second side 64 of substrate 60. As such, first portion 152 and second portions 154a, 154b of opening 150 are overetched, as described above.

As illustrated in the embodiment of Figure 10F, etching into substrate 60 from interfaces 155a, 155b toward first side 62 and second side 64 continues such that third portions 156a, 156b of opening 150 communicate second side 64 of substrate 60 with first portion 152 of opening 150 and, therefore, first side 62 of substrate 60. In one embodiment, etching of third portions 156a, 156b continues such that third portions 156a and 156b communicate, as described above. As third portions 156a, 156b are formed by overetching respective second portions 154a, 154b, adjacent second portions 154a, 154b directly communicate. Preferably, etching of third portions 156a, 156b of opening 50 at an angle from interfaces 155a, 155b toward first side 62 and second side 64 minimizes lateral or horizontal areas of opening 150 through substrate 60 from second side 64 to first side 62.

Figures 11A and 11B illustrate one embodiment of a casting 170 of a pair of openings 150' formed through substrate 60, according to the present invention. Each opening 150' includes first portion 152, a plurality of second portions 154a, 154b, 154c, and a plurality of third portions

156a,156b,156c,156d,156e formed in manners similar to those described above. More specifically, third portions 156a,156b,156c,156d,156e are formed by etching along high-index planes of substrate 60, as described above. As such, first portion 152, second portions 154a,154b,154c, and third portions 156a,156b,156c,156d,156e communicate to form openings 150' through substrate 60. As such, each of the combined openings 150' created by first portion 152, second portions 154a,154b,154c, and third portions 156a,156b,156c,156d,156e are illustrated in solid form by casting 170.

Figures 12 and 13 each illustrate a pair of openings formed through substrate 60 according to the present invention. As illustrated in the embodiment of Figure 12 openings 150a and 150b each include first portion 152 formed from first side 62 of substrate 60, a plurality of second portions 154 formed from second side 64 of substrate 60, and a plurality of third portions 156 formed between respective second portions 154 and first portion 152, as described above. As such, first portion 152 of each opening 150a and 150b forms a single elongated slot in first side 62 of substrate 60 and second portions 154 of each opening 150a and 150b form a plurality of spaced slots in second side 64 of substrate 60. Thus, by forming openings 150a and 150b with spaced slots in second side 64, a single elongated trench in second side 64 of substrate 60 is avoided. Accordingly, strength of substrate 60 is enhanced and workable or useful area of second side 64 is increased.

As illustrated in the embodiment of Figure 13, openings 150a' and 150b' each include first portion 152 formed from first side 62 of substrate 60, a plurality of second portions 154 formed from second side 64 of substrate 60, and a plurality of third portions 156 formed between respective second portions 154 and first portion 152, as described above. By forming openings 150a' and 150b' with spaced slots in second side 64, openings 150a' and 150b' can be staggered and/or offset. As such, spacing between adjacent openings 150a' and 150b' can be reduced while maintaining substrate design restraints such as strength and backside support and/or adhesion area between openings 150a' and 150b'.

As illustrated in the embodiments of Figures 12 and 13, first portion 152 of openings 150a and 150a' forms a first slot in first side 62 of substrate 60 and first portion 152 of openings 150b and 150b' forms a second slot in first side 62 of substrate 60 such that the first slot and the second slot are spaced from each other and form a pair of first side slots in substrate 60. In addition, second portions 154 of openings 150a and 150a' form a first plurality of slots in second side 64 of substrate 60 and second portions 154 of openings 150b and 150b' form a second plurality of slots in second side 64 of substrate 60 such that the first plurality of slots are aligned with the first slot in first side 62 of substrate 60 and the second plurality of slots are aligned with the second slot in first side 62 of substrate 60. Thus, the first plurality of slots in second side 64 form a first plurality of second side slots in substrate 60 and the second plurality of slots in second side 64 form a second plurality of second side slots in substrate 60.

In one embodiment, as illustrated in Figure 12, the first plurality of slots in second side 64 and the second plurality of slots in second side 64 are substantially aligned with each other. In another embodiment, as illustrated in Figure 13, the first plurality of slots in second side 64 and the second plurality of slots in second side 64 are staggered or offset with each other. As such, spacing between openings 150a' and 150b' including, more specifically, spacing between first portions 152 of openings 150b and 150b' can be reduced, as described above. In one embodiment, as illustrated in Figures 11A and 11B, with the first plurality of slots in second side 64 and the second plurality of slots in second side 64 being staggered or offset with each other, spacing between openings 150a' and 150b' is reduced such that the first plurality of slots in second side 64 and the second plurality of slots in second side 64 overlap. More specifically, by interleaving or overlapping the first plurality of slots in second side 64 with the second plurality of slots in second side 64, spacing between first portions 152 of openings 150b and 150b' can be further reduced.

While the above description refers to the inclusion of substrate 60 having opening 50 (including openings 50', 150, 150') formed therein in an inkjet printhead assembly, it is understood that substrate 60 having opening 50 formed therein may be incorporated into other fluid ejection systems including

non-printing applications or systems as well as other applications having fluidic channels through a substrate, such as medical devices. Accordingly, the present invention is not limited to printheads, but is applicable to any slotted substrates.

- 5 Although specific embodiments have been illustrated and described herein for purposes of description of the preferred embodiment, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent implementations calculated to achieve the same purposes may be substituted for the specific embodiments shown and described without
- 10 departing from the scope of the present invention. Those with skill in the chemical, mechanical, electro-mechanical, electrical, and computer arts will readily appreciate that the present invention may be implemented in a very wide variety of embodiments. This application is intended to cover any adaptations or variations of the preferred embodiments discussed herein. Therefore, it is
- 15 manifestly intended that this invention be limited only by the claims and the equivalents thereof.

What is Claimed is: